300mm Factory Design for Operational Effectiveness

Bruce Sohn
Intel Corporation
Fort Worth, TX

Devadas Pillai
Intel Corporation
Chandler, AZ

Noel Acker
Intel Corporation
Santa Clara, CA

Biography

Bruce Sohn is Fab 16 Plant Manager and Operations Program Manager for Intel's 300mm Technology. Bruce has worked on more than a dozen process start-ups and had a variety of engineering, design and operations jobs in his 17 years at Intel. He received his degrees in Materials Science and Engineering from the Massachusetts Institute of Technology.

Dev Pillai is Director of Operational Decision Support Technology at Intel Corporation and is responsible for Factory Integration & Standardization of 300mm equipment and Automation systems. He has been at Intel 16 years. Dev has a BS in Mechanical Engineering, an MSE in Computer Aided Processes and a Masters in Business Administration.

Noel Acker is Manager of Facility Technology Design Integration at Intel. He has been with the company for 20 years. Noel received his Bachelor's Degree in Mechanical Engineering from the University of California Davis and his Masters in Mechanical Engineering from the University of Washington.

Abstract

Semiconductor Fabs are billion dollar facilities designed to produce product rapidly and to recoup costs in a very short time period. Companies have responded to increased competition by optimizing all aspects of the product supply line. Optimization includes product design, process design, facility design and inventory management. This paper reviews the key aspects of operational effectiveness and applies those needs to factory design. The industry conversion to 300mm provides an ideal opportunity to restructure the basic facility model around the new demands imposed by the larger wafer size.

In considering areas to optimize, the facility design engineer must consider process requirements, factory layout and automation aspects. Fully automated 300mm facilities place less emphasis on the production lot to human interface and more emphasis on the equipment to human interface.

An efficiently designed factory will not only improve the ability to install and maintain automation systems but will facilitate the technician's ability to maintain process equipment and continually monitor the performance of the factory.

Additionally, a well tuned facility will have tool capacities matched in a manner that ensures the best possible flow of material.

Introduction

The purpose of any manufacturing facility is to reliably reproduce a series of steps in order to provide a product that will be purchased by a customer. Fab processes must not only reproduce the features of the integrated circuit but also achieve the highest levels of quality at the lowest possible cost and the fastest cycle time.

This combination of requirements is necessary to ensure that the company can generate the profits mandated by its shareholders and to satisfy continuously changing requests from customers.

Historically, tasks within a semiconductor Fab were handled by technicians who were skilled with a combination of process, equipment and operational responsibilities. Because of the large number of WIP movement tasks, the design of the factory was typically optimized to ease the technicians' ability to move material. Hence, operations were aligned to the process flow; workstations were designed for ergonomic efficiency and facilities were constructed to support these needs.

The semiconductor industry conversion to 300mm wafers drives several important operational changes. These changes include added concerns about ergonomic handling and larger inventory management systems to handle the wafers and carriers. The systems used to manage these changes will significantly impact the efficiency and effectiveness of the overall Fab. The magnitude of these changes suggests that Fabs are in the midst of an operational inflection point—a point where significant change, if appropriately leveraged, can have dramatic implications to corporate performance.

Operational Effectiveness Defined

While operational effectiveness can be defined in financial terms (e.g. profit) or equipment performance terms (e.g. OEE); for the purposes of this paper, effectiveness is defined as the ease by which a Fab can generate product per specification. Indicators include at least three key parameters: cycle time, production costs and technician ease of operation. The first two are objectively derived. The third is more subjective but, by its nature, has a significant impact on both cycle time and costs.

Production costs can be divided into two major components, those occurring as a part of normal operations (e.g. silicon or labor costs) and those that are designed into the infrastructure (e.g. equipment and facilities). Each of these is an important component of wafer cost.

Facility costs are optimized through material selection, Fab design and tool layout. Factory design and layouts are discussed below.

Operational costs are minimized by designing the operational flow in a manner that prevents rate-limiting steps in the overall set of processes. In earlier generations, efficient wafer flow was achieved by shortening the distances that the wafers needed to travel. This technique shortened the flow from the perspective of the wafer and the manufacturing technician. With fully automated facilities, the time to deliver a lot to a station is small and essentially constant. Thus, Intel now designs its factories to ease the technicians' ability to maintain tools rather than moving the material. In this model, like tools are placed together with the maintenance sides (rather than load ports) facing each other.

AMHS Features for Operational Effectiveness

The selection and configuration of 300 mm AMHS equipment is based on the AMHS technology capability and supplier's ability to demonstrate integrated systems that meet or exceed several key needs. These included safety requirements (incident and injury-free initiative), reduced total cost of ownership, system footprint, high throughput, ease of use, layout and installation flexibility, higher reliability and increased maintainability. In addition, due to frequent changes in process technology, there is an underlying need to ensure whatever system is installed upfront is capable of providing extendibility, flexibility, and scalability [5] beyond what was originally intended.

Interbay - Overhead monorail with Active vehicle

Operational requirements in a factory drive the need for reliable and uninterrupted high throughput material movement across long transportation distances. Overhead monorail transport systems were chosen because of their superior throughput capability, smaller footprint, and ability to run multiple loops at highest throughput. Overhead monorail also eliminated potential safety hazards of people having to co-exist with ground-based systems along aisles and corridors. The stacked rail configuration, shown in Figure 1, was used as the standard configuration for high volume interbay delivery. This design reduces shadow footprint in the cleanroom. The active vehicle technology is used in interbay vehicle designs because it provides significant cost reduction advantages over conventional passive vehicles that have more robots. Active designs also provide a path for adding future interoperability between track (from one supplier) and stockers (from a second supplier). The standards established by SEMI make this 'mix and match' solution viable.

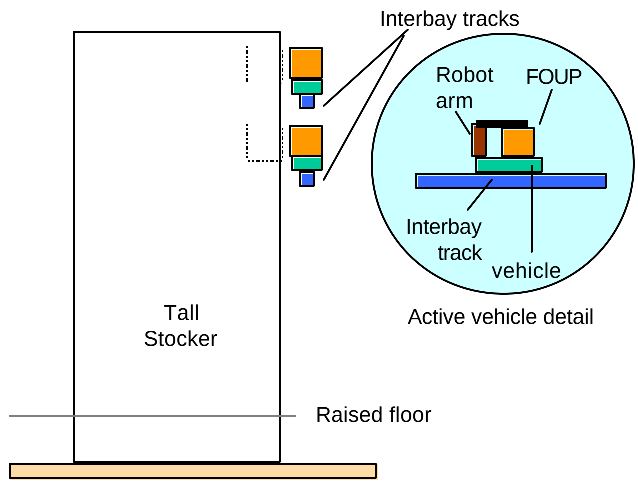

Figure 1 Stacked Interbay Tracks And Active Vehicle

Intrabay - Overhead Hoist Transport (OHT)

In 200mm, Intel used rail-guided vehicles (RGV) in Diffusion and Lithography bays. RGV provided very high throughput capability. However, the rail in the floor compromises factory layout flexibility. With process life cycles of only two years, flexibility is very important. Additionally, floor-running robotic vehicles are inconvenient to factory personnel.

In 300mm, Intel worked extensively with international consortia (i300i and J300) in the concept and development of the Overhead Hoist

Transport (OHT). The system shown in Figure 2 consists of a rail slung from the bay ceiling carrying multiple vehicles with FOUP hoisting capability. Each overhead hoist vehicle (OHV) performs the loading and unloading of FOUPs from the process equipment load ports in the bay. Multiple vehicles are added to the loop to increase the throughput capability.

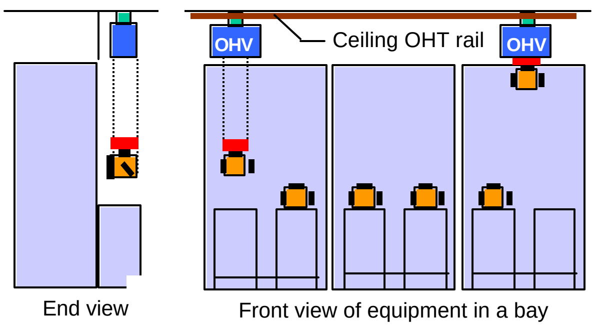

Figure 2 Overhead Hoist Vehicles for Intrabay

There are several reasons why the OHT is selected for Intrabay. The main advantage of OHT is its low use of floor space. The shadow footprint occupies the unused zone above load ports and does not take up additional cleanroom space. This enables more narrow bay width compared to floor running systems. Because of the very high cost of cleanroom space, the OHV permits greater wafer output per square foot.

Another major advantage of OHT is that factory personnel and vehicles do not co-exist in the same floor space. This significantly reduces bay congestion and greatly improves safety. Other key differences are outlined in Table 1.

Selection of an ideal intrabay automation solution is difficult because the analysis must assess multiple criteria and weigh risks. Intel chose OHT intrabay technology for operational reasons. Integrated system reliability will be demonstrated during technology development—prior to large-scale deployment in high volume manufacturing.

The selection and design of the AMHS systems provided the framework for designing the facility.

Key operational requirements considered	AGV	RGV	OHT
Throughput capability	High	Very high	Very high
Routing flexibility	Excellent	Poor	Good
Adaptability to bay layout changes	Excellent	Poor	Good
Extensibility to bay throughput increases	Good	Good	Very Good
Bay width needed (wide bays negatively impact factory output)	Wider bays	Wider bays	Narrow bays
100% Intrabay AMHS capital cost	Higher	Higher	Lower
Intrabay System reliability	Good	Good	In Testing

Table 1 Contrasting Intrabay Technologies Based on Operational Needs

New 300mm Fab Design

In 1996, the Intel requirement for new fabrication space was increasing at a rapid pace and capital spending was skyrocketing into the billions of dollars per year. Reducing facility construction cost became a priority and an aggressive goal of >30% facility cost reduction was established. At the same time, conversion to 300mm wafers and new process technologies offered new challenges, and opened a window of opportunity for facility design changes.

To meet these needs, a Facility Design Task Force was chartered by Intel to develop the Next Generation Fab Design Concept. The goal was to:

1) Create a Standard Design for at least the Next 2 Generations of Process Technology.
2) Maintain compatibility with both 200mm and 300mm wafers.
3) Substantially reduced capital and operating costs compared to previous Intel Fab designs.

The Task Force evaluated various “revolutionary” and “evolutionary” design concepts being used or proposed around the world at that time. Some of the revolutionary concepts included: Windmill Fab [11], Ohmi Fab [12], Silo Fab [11], Functional Pod Fab [13], and Wu Airport Fab [14]. Concepts currently being used by other companies as well as some new Intel concepts were also evaluated. These consisted of total down-flow, slab-on-grade, stacked Fabs, and three new concepts developed by Intel. One of the Intel evolutionary approaches was chosen due to

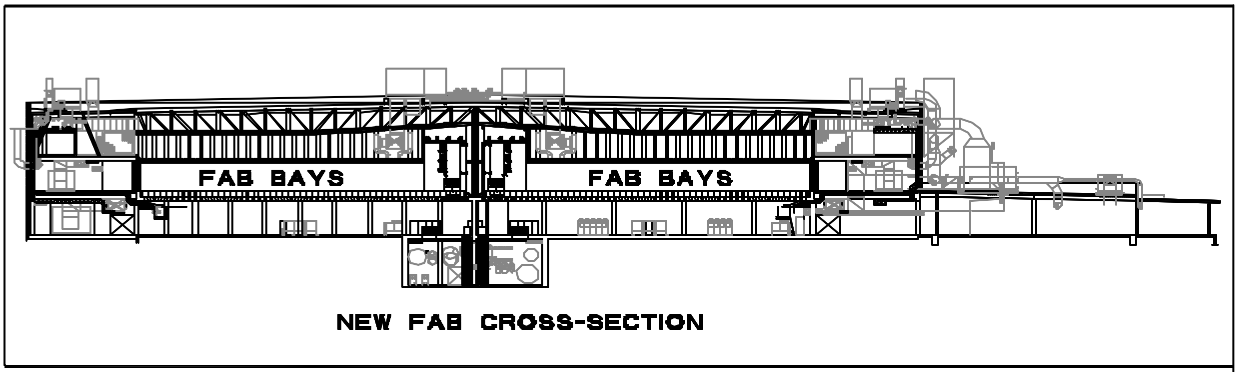

Figure 3 Fab Cross Section

"Copy Exactly" advantages when converting older Fabs, and the lack of a compelling reason for a radical change.

Reduced Cost Fab

The first element in reducing cost was to minimize the amount of building space constructed for the same wafer start output. Previous Intel Fabs had a total building space to Fab manufacturing area ratio of approximately 10:1. The new design reduced this to approximately 4.2:1.

Eliminating the fan attic, penthouse, and 80% of the basement from previous Intel designs (Figure 3), as well as optimizing support room sizes significantly reduced building overall volume. Total building height was reduced from approximately 90 ft, which required special Code approvals, to less than the Code limit of 55 ft.

The Fab cleanroom and subfab, which are critical to the tool environment and wafer manufacturing, remained essentially unchanged from previous Intel designs. This simplified the Copy Exactly manufacturing transfer process, and minimized concerns about retrofitting existing buildings to run the new processes. By eliminating non-critical building support space, the amount of concrete and steel was reduced by almost 50%, and significant reductions in HVAC, lighting, and fire protection were achieved. This had a snowball effect on all areas of the project cost.

An integral part of the new design was a revised cleanroom air recirculation concept. Previous Intel designs had a concrete-floored fan deck over the entire cleanroom free-span area, with 26kcfm recirculation fans distributed to match the cleanroom layout. Future fan cutouts and utilities were provided to allow moving the fans for future layout changes. The new design replaced the concrete fan deck with a lightweight sheet metal plenum barrier, and substituted 69 kcfm fans located at the perimeter of the cleanroom. This reduced the number of fans by 62%, gaining economy of scale, and reducing piping and facility monitoring points required. In addition, eliminating the massive concrete fan deck allowed trusses and supporting steel to be reduced by one half, and simplified dynamic seismic design of the building. Since the fans feed a common plenum, future layout changes no longer impact the air delivery system, and redundant ZUD (Zero Unscheduled Downtime) units are minimized.

Additional simplification of the structure is achieved by eliminating the basement under the entire cleanroom subfab. The basement requires large concrete columns every 12 ft x 12 ft to meet Fab vibration specifications two levels above and was used mostly for duct and pipe mains to feed subfab distribution laterals above. By controlling the aspect ratio of the building, and simplifying the utility distribution scheme, the mains were concentrated in a central utility trench, eliminating the need for a basement, and significantly reducing the amount of large ductwork and piping required.

Additional reduction in cost is achieved by reducing the vibration specifications on the non-Litho half of the cleanroom from 250 micro-inches/second to 2000 micro-inches/second. This eliminates 75% of the subfab columns on the lower rated side of the building. The waffle-slab thickness is also reduced from 28 inches to 19 inches. The elimination of columns on the non-Litho side has a secondary benefit of providing more useable subfab space for tool support equipment.

Bridge Building

A second contribution in the quest for a lower cost Fab was the idea of a Bridge Building (Figure 4

Bridge Building). The bridge connects two 100,000 square foot Fabs with a less expensive building where shared support functions and less critical manufacturing operations are housed. Common spaces, such as parts cleans, labs, gowning, storage, support rooms, wafer bumping, shipping/receiving, and some selected Fab manufacturing operations can be shared between the two Fabs, thereby optimizing space, and reducing overall cost.

The bridge building uses lower cost construction and utilizes much of the subfab level spaces for occupied rooms whereas the Fab building subfab is reserved for utilities and tool support equipment only. In order to achieve the reduced cost, some amount of flexibility is sacrificed and the design of the Bridge must be carefully coupled with the operational layout. Floor penetrations and free subfab space are constrained and floor vibration specifications are reduced to 2000 micro-inches/second. Currently, the only Fab manufacturing spaces planned for the bridges are Implant and Planar.

Another benefit of connecting two Fabs together is the ability to use a common Central Utility Building and Waste Collection Pit. By sharing redundancy between two Fabs, substantial cost savings are achieved.

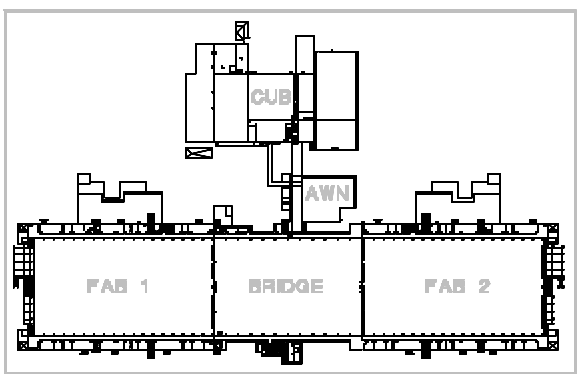

Figure 4 Bridge Building

Value Engineering

The new Fab design and addition of the bridge building moved us substantially closer to achieving our cost targets, but additional cost cutting was required.

Previous projects had demonstrated how good design reduced facility system costs through extensive Value Engineering (VE). These facility system designs were used as a baseline for the new facility and additional VE changes were proposed. A Financial Cost Model, which took into account ten years of operating and capital costs, was used for decision-making. This ensured that initial cost cutting was not achieved at the expense of long-term costs.

300mm Facility Impact

At the early stage of design development, very little was known about the impact of converting from 200mm to 300mm wafers. By becoming involved early in the planning stages, the facility, AMHS, and tool design were optimized as a system.

Tall, 20 foot 300mm stockers and a centralized interbay AMHS (were integrated into the building design from inception. The space under the stockers was used for utility main distribution to avoid any conflict with process tool utility penetrations. In addition, the ceiling grid was reinforced and seismically braced to support the 300mm OHT loads. These features are incorporated into the design with very little additional cost.

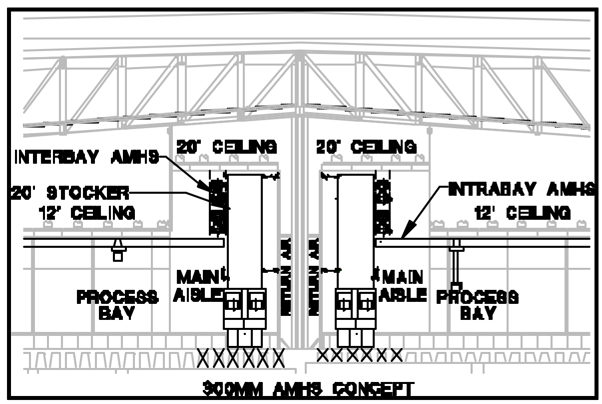

Figure 5 300mm AMHS integrated into the building design.

The baseline Fab design needed to be capable of at least Class 1 performance for existing 200mm processes. Conversion to 300mm presented an opportune window to consider changes to established operational methodologies and facility design constraints. The size and weight of 300mm wafer carriers dictates some form of automated material handling due to ergonomic limitations. This has lead to the introduction of Front Opening Unified Pods (FOUPs) and better than Class 1 tool mini-environments as standards for 300mm tools. This provided us the opportunity to reduce the overall cleanroom to Class 100 and significantly reduce gowning requirements. Substantial capital and operational savings were possible by reducing cleanroom filters and recirculated airflow. An accompanying reduction in cleanroom temperature

specifications from 72 to 69 degrees F was made to enhance operator comfort with the reduced airflow.

300mm Utilities

A major concern in achieving our goals was that cost savings achieved in the new Fab design could easily be overshadowed by cost increases due to changes in utility system sizing and specifications for the 300mm tools and process technology requirements. Previous wafer size changes were accompanied by a 10%-20% increase in tool utility requirements. In addition, each new process technology was burdened with ever tightening facility specifications, new process chemical systems and more stringent environmental regulations. Site environmental discharge limits and total utility consumption levels are becoming limitations to site selection and growth. It was apparent that a proactive program to control equipment utilities and effluents was essential if we expected to have any chance of hitting our aggressive cost target.

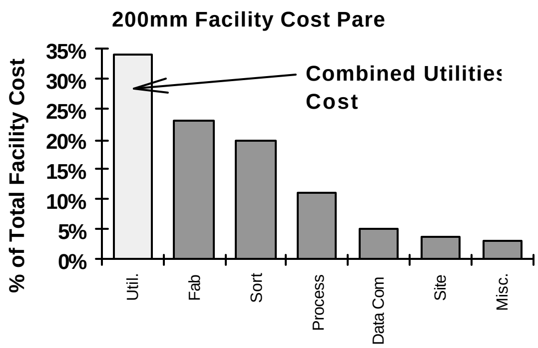

Figure 6 Facility Cost Pareto

Utilities infrastructure typically accounts for 34% of the Fab construction budget (Figure 6). Included in the tabulated utility costs are exhaust, ultra pure water (UPW), process electrical, and bulk process gas systems. Intel worked with 300mm tool suppliers early in the development cycle to help contain escalating utility consumption and environmental emissions. Additional industry impetus was gained when i300i ratified guidelines for future 300mm tools.

Another reason identified for high facility cost is over-design of facility systems due to the lack of accurate utility consumption data. Previously, tool suppliers greatly over specified utility demands and these over-designs were incorporated into the facility infrastructure design. Accurate 300mm tool utility characterization became an integral part of the tool utility reduction program.

To date, this effort has been partially successful, but a continuing effort is required for long term control and measurement of 300mm tool utilities and effluents.

By reducing total volume of the building, specifying space needs by tool type, integrating the automation system and value engineering, Intel achieved more than 40% reduction in Fab construction costs.

Fab Layout Features

Tall Central Corridors

Since FOUPs are significantly larger than 200mm boxes, stocker designs were reanalyzed. It was determined that a FOUP was 2X larger in weight and 3X larger in volume compared to a 200mm box. This increase in carrier size would have a detrimental effect on stocker storage density if conventional 12' tall stockers were placed on the raised floor. Data showed a 12' tall 300mm stocker resulted in a 60% reduction in storage density (carriers/square feet of cleanroom). The best 300mm option open was to make the stockers taller and place them on the Fab waffle slab. This design made 300mm storage density almost equivalent to 200mm.

As mentioned previously the 300mm-building design accommodated these tall stockers. The layout is shown below, which consists of a central 20 foot tall corridor which serves as the main corridor in the center as well as the location where stockers are installed.

Stacked interbay monorail loops link stockers together with loops traversing in opposite directions. The dual directional feature of the inter-bay system speeds delivery of material throughout the Fab.

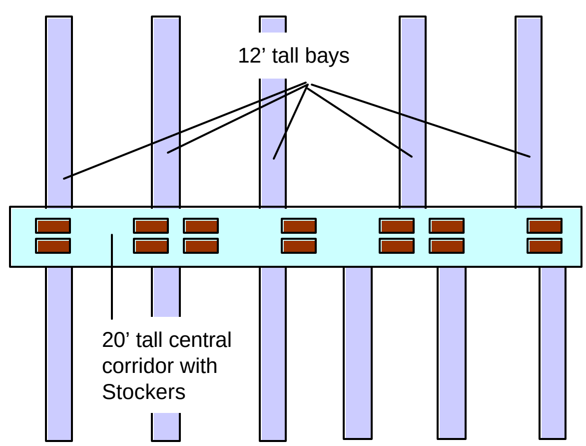

Figure 7 Showing tall central corridor housing Stockers

Stocker placement for layout flexibility

For 200mm Intrabay applications, with floor-running rail guided vehicles (RGV), stocker placement decisions were tied to the location of the Fab bays being serviced. This limitation, shown in Figure 8 below is referred to as bay-pitch dependent stocker locations. Bay-pitch dependent designs reduce flexibility by limiting process tool positioning. Reductions in total Fab output are also observed.

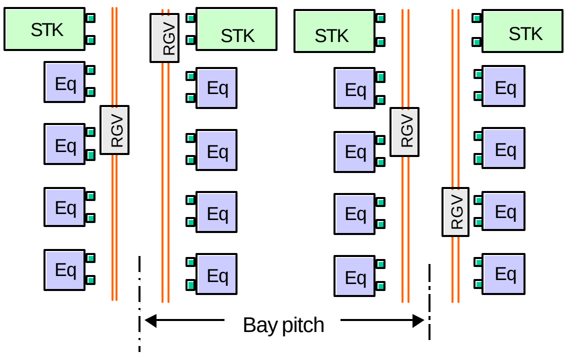

Figure 8 Bay pitch dependent Stocker locations

For 300mm, flexibility was enhanced by adopting a design where bay pitch remained independent of stocker location. Use of OHT for 300mm intrabay made this solution viable. Ceiling mounted OHT tracks mitigated the need to provide critical alignment of the stocker front end to the front end of the production equipment. This feature allows layout designers to explore enhanced layout options for 300mm that de-link the stocker location and permit it to be independent of the bay pitch, as shown in Figure 9 below. As process changes dictate layout changes, bays have the flexibility to move either to the left or right without the need for stocker relocation. Not only are costs reduced but the speed of ramping output is enhanced.

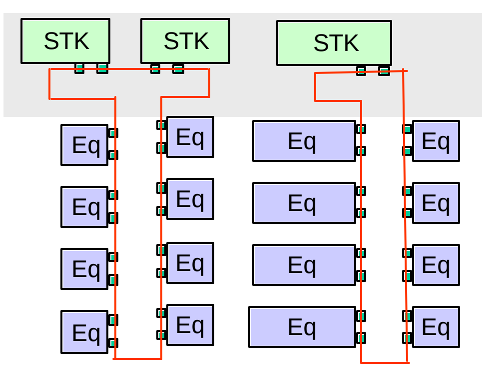

Figure 9 Bay Pitch Independent Stocker Locations

The intrabay OHT also permits more than two stockers to be linked to one intrabay loop thereby increasing buffering capability. Designs were also aided by the decision to place all stockers in the central core of the cleanroom, independent of the processing bays. This allowed AMHS system design to proceed at a pace independent of the date for determining the final production equipment placement in the layout. These improvements have also reduced the number of different stocker configurations.

A third layout option evaluated was the concept using one Intrabay loop to connect multiple bays together on a single loop. Figure 10 shows the many advantages of bay-pitch independence plus providing the capability of consolidating lots into fewer stockers. The material handling routing logic enables stocker robots and stocker storage levels to be automatically leveled resulting in balanced stocker robot utilization and more consistent delivery times and transportation times throughout the system.

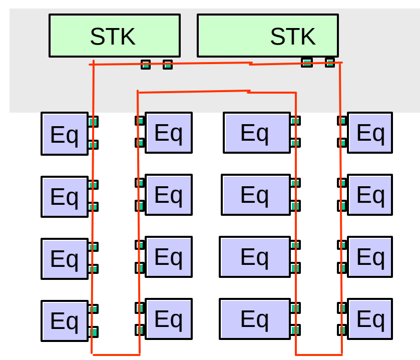

Figure 10 Bay pitch independent and multi-bay linking

Designs shown in Figure 9 and Figure 10 generated less need for stockers than the original design in Figure 8. At the same time, identical AMHS performance indicators were demonstrated in the simulations. Impact to Fab stocker and OHV quantities are compared in Table 2.

Layout Option	No. Of Stockers	No. Of OHVs
Figure 8	X	Y
Figure 9	0.7X	Y
Figure 10	0.6X	1.05Y

Table 2 AMHS configuration impacts of layout options

Since stocker quantities contribute most heavily to the overall cost of an AMHS, reductions in stocker quantities directly result in reduced capital costs. As it can be seen from Table 2, cost reduction is significant when aggregated across the entire factory. Adding the flexibility, again improves Intel's ability to respond to changing process and customer needs.

A throughput evaluation was performed for determining how many bays needed single OHT loops (un-linked bays) and how many bays needed to be linked together (linked bays) with one loop. The results showed that the split was almost equal. Thus, linking multiple low throughput bays with one loop was very beneficial, leading to lower interbay capital costs.

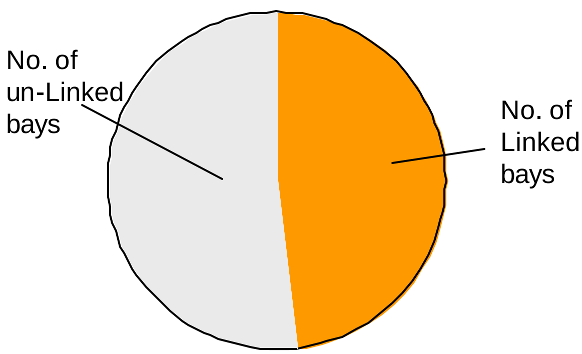

Figure 11 Linked Versus Un-Linked Bay Configurations

Comparing the advantages and disadvantages of linking multiple bays with one OHT loop is shown below.

Advantages of Linking	**Disadvantages of Linking**
~40% reduction in stocker quantities across the factory. Better system reliability, as there were fewer components. Provides significant AMHS cost savings. Reduces some of the moves on the Interbay transport loops. Reduces the number of OHT controllers in the Fab. Provides better load-leveling of stocker robot and stocker storage and therefore minimizing transport delivery time of most bays	Increases risk to the factory output if the OHT reliability is below specifications. Linking put s more production equipment on one loop. There could be some increase in the number of intrabay vehicles needed. Linking may increase the delivery time of some bays.

Table 3 Advantages And Disadvantages Of Linking Multiple Bays With The Same OHT Loop

Chase Layouts Are More Important Than Bays

Operational tasks in a 300mm factory are significantly altered once large-scale implementation of intrabay technology is employed. Full intrabay eliminates the need for production personnel to load and unload production equipment in bays. As a result, people tasks transition from loading/unloading tools (generally performed at the loadports in the front of the tool in the bay) to mostly maintenance and repair (generally performed at the rear of the tool in the chase). This paradigm change results in a major shift in the way bays are laid out. Since technicians are going to be found in the chase side of the factory most of the time in such a scenario, chase layout becomes much more important than bay layouts.

Arranging similar tools in a bay, based on micro-flows to optimize manual movement of material is no longer needed. 300mm chase layouts designed for optimizing maintenance becomes the focal point versus the old 200mm method of bay layouts for operational simplification. Consequently, a layout that ensures similar production equipment sharing the same chase (clustering of like tools in each chase) becomes the norm as shown in Figure 12.

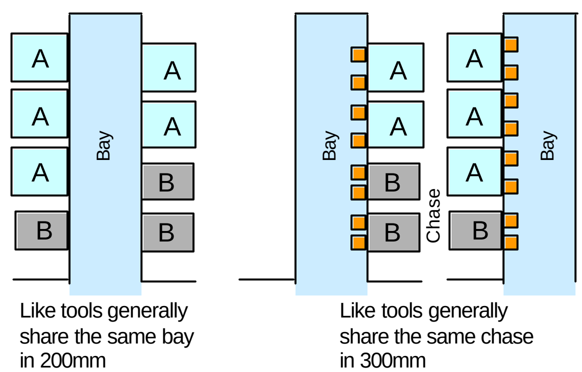

Figure 12 Chase layouts designed for maintenance ease will become the norm for 300mm.

Location of Metrology equipment in the layout

Full, 100%, intrabay factories require traditional metrology equipment placement rules in the layout to be re-examined. Three considerations are made when placing metrology tools: proximity to the process tool being monitored; centrality; and placement so as not to encumber the placement of process tools.

Cycle time is shortened by placing metrology tools adjacent to process tools and on the same OHT intrabay loop as shown in Bay 1 in Figure 13. A second approach is grouping them together to

minimize the number of metrology tools as shown in Bay 2 in Figure 13. This technique also facilitates maintenance and technician intervention. In this case, the feeding process tool may not be on the same OHT loop. The third approach is first ensuring major process tools fit in the layout and then finding opportunistic locations for metro tool insertion. Here the metro tool also may not be connected to the same OHT loop.

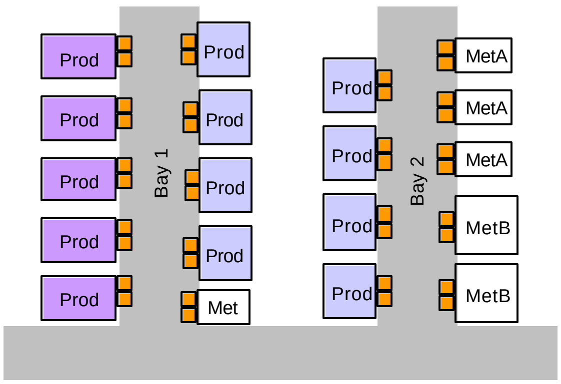

Figure 13 Showing distributed and centralized metrology

Operational Control Centers will be needed

In a fully automated 300mm factory, operational control centers are employed to continually monitor production equipment and facility systems. From these monitor points, technicians are dispatched in an effort to maintain production without interruption. New production priorities are also set from these control centers.

Control center location in the layout will be a key challenge for the automated 300mm factory. There are several placement options. The sketch below shows two options of control centers in 300mm.

By placing control centers within functional areas communication to the technicians in the area are greatly facilitated. Should problems arise, monitoring is greatly simplified.

Placing all control centers in a single, centralized location of the facility permits more global monitoring of systems and facilitates improved optimization of the operations. Dispatching, however, may be complicated due to the distance between the monitoring point and the actual problem. The choice of actual location is driven by the reliability of the process equipment, the automation systems and the production process.

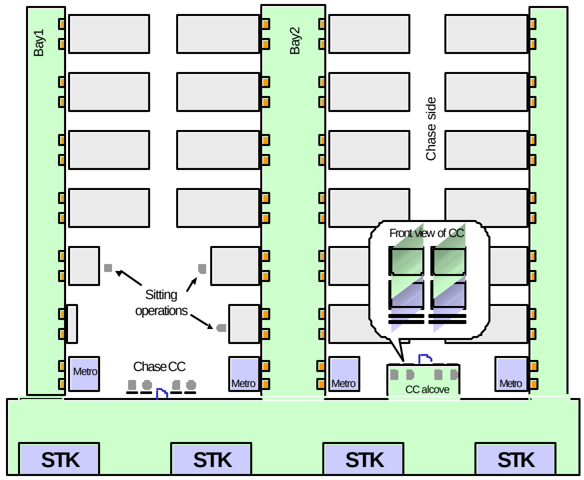

Figure 14 Sketch showing possible Control Center (CC) locations

Capital Purchase Model

The purchase of capital equipment will have a large impact on the overall effectiveness of the factory. Balanced capacity models fail to produce the wafer output predicted by static models. This is the result of dependent events and random variation within the daily operations.

In order to maximize flow, tool purchases can be purchased so that the constraint is continuously fed by non-constraint tools. The constraint is the tool where production utilization is equal to production availability. Non-constraints must have sufficient protective capacity to ensure that constraints are continuously buffered against upstream performance issues.

Conclusion

The quest for the optimal Fab design is a never-ending process of continuous improvement. This paper has shown how adopting pre-determined operational goals and integrating the overall design can have a dramatic impact on operational performance.

Factory output can be maximized while reducing costs, reducing cycle time and improving technician ease.

Fully automated 300mm facilities provide the best opportunity yet to optimize overall operational performance. Intel's conversion to 300mm is driven by a need to reduce costs and these design concepts enhance our ability to achieve that goal.

References

[1] Global Joint Guidelines for 300mm Factories, I300I/J300 Factory Integration synergy, Sematech Web site.

[2] Devadas Pillai and S. Srinivasan, "Material Handling Automation in 300mm Wafer Fabrication Facilities", ISSM paper, Tokyo, 1996.

[3] Paolo Gargini and Dev Pillai, "Integrated factory designs for 300mm facilities" SEMICON Japan, December 1997.

[4] Eddy Bass and Dev Pillai, "Importance of Factory Standardization for 300mm Cost Reduction," SEMICON Kansai, 1999.

[5] Noel Acker and Keller Kuhner, "Intel's New Reduced Cost 300mm Fab Design Concept and 300mm Utilities Reduction Program", Intel Internal Conference Paper, 1998.

[6] International Technology Roadmap for Semiconductors, Factory Integration Chapter, December 1999.

[7] Dev Pillai, Tim Quinn, Ken Kryder, Dan Charlson, "Integration of 300mm Fab Layouts and Material Handling Automation," ISSM paper, Fall 1999, San Jose, CA.

[8] Daniel Seligson, "Planning for the 300mm Transition," Intel Technology Journal, Q498, URL: http://developer.intel.com/technology/itj/q41998/articles/art_4.htm .

[9] Bruce Sohn, Anthony L. Romero, Sam Mouck, "Designing Fabs for High Performance," Proceeding of The Fifth International Symposium on Semiconductor Manufacturing, October 1996, Tokyo, Japan.

[10] Bruce Sohn and John Willbrandt, "Intel's 300mm Manufacturing Operations Vision and Roadmap," Report to Intel's Manufacturing Operations Strategic Capability Segment, Fall 1998.

[11] Kishore Potti, SEMATECH Factory Architecture & Operational Analysis (FIPC002), "300mm Revolutionary Designs," July 2, 1996.

[12] Tadihiro Ohmi "Breakthrough for Scientific Semiconductor Manufacturing in 2001," 1992.

[13] Ken Moyle, "Touchstone Final Report," Intel Internal Document, 1989.

[14] Bevan P. F. Wu, "Intelligent Microelectronics Manufacturing and the Issue of Semiconductor Equipment Design," SEMICON/Korea Technical Proceedings II, Nov. 18-19, 1992, Seoul Korea, pp. 141-146.

Acknowledgments

The authors gratefully acknowledge contributions and critiques from numerous individuals and teams in several Intel organizations. This work summarizes only a portion of the development done in the last five years. Thanks to all that have contributed their vision and energy.